Fermilab

Fermilab Electron Accelerator-based Research Program

Department of Energy

Office of High Energy Physics

Review of Electron Accelerator-based Research

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Table of Contents

I. Introduction

There is consensus within the community that the energy frontier machine after the LHC should have both the capability of precision studies of the new physics observed at the LHC and the capacity to extend the discovery reach for new physics beyond the LHC. Lepton colliders seem to be attractive candidates for such a machine and the choice of the community is currently the International Linear Collider (ILC), an electron-positron collider with a center-of-mass energy of 500 GeV – 1 TeV, provided this energy is sufficient to follow up on LHC discoveries. The Fermilab electron accelerator based research program supports the scientific activities for the development of detector concepts at electron-positron colliders and the development of new detector technologies needed for those new facilities. Most of our detector research efforts to date, although generic in nature, have been carried out in the framework of the ILC. This work has also benefited directly the development of detectors for CLIC, since the detectors proposed for CLIC are adapted versions of the ILC detector. All scientist effort on this detector R&D is reported to the budget category under review.

Another option for a lepton collider is a Muon Collider, which offers a number of potential advantages including compact size. The development of a Muon Collider also provides a range of intensity frontier physics opportunities associated with the accelerator complex needed to produce the required intensity of muons. Recently a Muon Accelerator Plan (MAP) has been submitted with a Design Feasibility Study Report (DFSR) for a multi-TeV Muon Collider as one of the main goals. It includes an end-to-end simulation of the Muon Collider accelerator complex using demonstrated, or likely soon-to-be-demonstrated, technologies and an indicative cost range. The MAP proposes investments in the basic research to prove the viability of the concept of cooling muons and accelerating them to high energy with collision luminosities sufficient for physics studies. An associated, and equally important, question is if detectors can be built that will withstand the interaction region backgrounds and are sufficiently sensitive to pick out the physics with the required precision. Without a positive answer to this second question the Muon Collider is not a viable option. The MAP proposal therefore explicitly refers to the need for an accompanying Physics and Detector study. Although the KA12 budget category explicitly refers to electron accelerator based research, we note that the new activity on Muon Collider physics, detector and background studies is not presently supported under any explicit budget category. Given their nature, it would seem natural to support the scientific effort on these Muon Collider detector related studies under KA12.

New accelerating techniques and detector concepts are born from the imagination and initiative of researchers at universities, national laboratories and industry. Without innovations in detector technology the reach and success of experiments in particle physics will be limited. Particle detectors with unprecedented precision will be required in order to penetrate and uniquely determine the structure of the fundamental interactions. Some may use existing technologies employed at a scale currently unreachable; others may adopt promising nascent technologies for the field of particle physics; still others may utilize technologies that have not been thought of yet. Our detector R&D efforts are geared towards the development of challenging, but potentially transformational technologies. The detector R&D program will leverage the various areas of expertise of the laboratory and, when possible, emphasis will be given to the development of enabling technologies that are likely to have broad applicability beyond lepton collider detectors.

The following sections of this report describe how Fermilab has used and proposes to use its electron accelerator based resources to advance the goals of US particle physics. This discussion is cast in the context of detector R&D for e^+e^- and $\mu^+\mu^-$ colliders. Although tactics may change year-to-year in response to scientific and technical developments in the field, these strategic goals will broadly serve and advance the US HEP community in the pursuit of particle physics.

II. Progress Report

Fermilab has a strong track record in the design of detector concepts at new facilities and the development of new detector technologies. It has successfully equipped many generations of experiments that employ these new detection techniques. The CsI calorimeter for KTeV, the liquid argon calorimeter and scintillating fiber tracker for Dzero, and the silicon vertex and tracking detectors for the collider experiments are just some of the achievements of our work. It is the development of new break-through technologies that will enable the next generation of experiments to achieve their physics goals.

Currently, the only tool we have available to directly study the energy frontier is a collider. The US has ceded the energy frontier to the Large Hadron Collider (LHC). Major upgrade programs are planned to fully exploit the physics reach of the LHC. Furthermore, there is a consensus within the high-energy physics community that, when the LHC has run its course, the next machine to precisely measure the underlying physics, which the LHC might reveal, is a lepton collider. The detectors at an upgraded LHC or at a future lepton collider are by necessity precision detectors. These detectors will not only need to supplement the physics program of the first phase of the LHC, but in case of lepton colliders, will have to significantly improve on the physics output of the full LHC program. Particle detectors with unprecedented precision will be required in order to penetrate and uniquely determine the structure of the fundamental interactions. Innovations in detector technology are required to reach this goal, and detector R&D at the energy frontier is a necessity for the vitality and viability of the field.

During the last three years we have embarked on a targeted R&D program that, if successful, could have a major impact, not only for lepton colliders, but the field as a whole. One example, is the consortium for the development of 3D vertically integrated silicon technology for particle physics that Fermilab has started as the first in the field. In 2007 we received the first 3D vertically integrated readout chip, which was fabricated at MIT-Lincoln Laboratories, for the readout of an ILC pixel detector. Over the course of the last year we have built a large international collaboration and are the lead institution for the development of this technology. In this role we have successfully organized a Multi-Project Wafer (MPW) run. We have built a facility for the characterization of silicon photomultipliers (SiPM's) and have demonstrated the feasibility of these photo-detectors for the readout of scintillator strips for a muon detector system. We have also started a Monte Carlo study of the feasibility of total absorption dual readout calorimetry. Initial results show that unprecedented hadronic energy resolution can be achieved in a lepton collider environment.

In the next three years we plan to bring these technologies to a level of maturity where we can start building small prototype detectors for LHC upgrades or future lepton colliders. In addition we have started to initiate a Muon Collider physics and detector work program. This program will encompass the design of a Muon Collider detector utilizing technologies that are able to handle the environmental backgrounds and at the same time study the physics reach of such a facility in the context of the reach of other lepton colliders. The remainder of this section will describe the progress in the areas of silicon, calorimetry, scintillators. We will conclude this section with a brief summary of what has been done to date in the area of a Muon Collider physics and detector program.

Silicon

Over the past several years the electronics industry has recognized that the continuation of Moore's law in IC technology by decreasing feature size will become limited by physical constraints of lithography, transistor scaling, and interconnect density. As an alternative, the integrated circuit industry is exploring vertical integration or "3D" as it commonly called. 3D integration is defined as the vertical integration of thinned and bonded silicon integrated circuits with vertical interconnects between the IC layers. This achieves increased interconnect and transistor density, while keeping the device area small. These emerging technologies, which enable heterogeneous integration of IC technologies, dense packing of transistors, and close integration of sensors and electronics, have obvious application for HEP detectors as well as for x-ray detection, electron microscopy, imaging, and other scientific applications. Fermilab was the first high-energy physics laboratory to recognize the potential of 3D integrated circuits for particle physics, and in 2006 we began a focused R&D program to explore this technology. Fermilab is currently recognized as the world leader in exploring this technology for high-energy physics applications. Based on Fermilab's early work, 16 international laboratories have joined Fermilab to form a consortium for the development of 3D integrated circuits in such areas as the LHC, ILC, B factory, and X-ray imaging, to name a few. The work at Fermilab has helped lead industry to consider offering 3D multi-project foundry runs to the scientific community at large.

The R&D program at Fermilab embraces an integrated approach by studying all aspects of integrated detectors, including 3D circuit design, thinning of circuits for low mass applications, and researching new bonding technologies to replace conventional bump bonds in demanding applications. In addition, Fermilab is exploring alternative technologies, such as SOI (Silicon On Insulator) and is active in studying the application of silicon-based photo-detectors to particle physics. All of the R&D on pixel detectors is carried out by the "Fermilab pixel group", led by Ray Yarema and Ron Lipton and includes Dave Christian, Bill Cooper, Marcel Demarteau, Gregory Deptuch, Jim Hoff, Farah Khalid, Simon Kwan, Alpena Shenai, Lenny Spiegel, Marcel Trimpl and Tom Zimmerman.

3D Integration: MIT-Lincoln Laboratory (MIT-LL) has developed a 3D integration process based on oxide bonding of multiple layers of 180nm SOI CMOS wafers. We realized that their 3D process was a very promising path to achieving the low mass, high position resolution, and good time stamping performance necessary for an ILC vertex detector. In 2006 we submitted a 3-tier vertically integrated pixel (VIP1) chip for an ILC vertex detector to a DARPA-sponsored 3D run at MIT-LL. The chip contains an amplifier/discriminator with double-correlated sampling, digital and analog time stamps, and sparse readout in a 64x64 array of 20-micron pixels. The height of the three tiers of electronics was a mere 22 microns. The 3D chips were received about one year after submission of the design. Our chips were functional, but had low yield and larger leakage currents than anticipated. Based on our experience with the first devices, a new design called VIP2a, with functionality nearly identical to the VIP1, but with more conservative design rules and 30-micron pixels was submitted to the following MIT-LL DARPA run. These second generation chips are expected in the summer of 2010.

In addition to working with MIT-LL, Fermilab started collaborating with Tezzaron Inc., based in Naperville, IL. Tezzaron has developed the first commercially available 3D IC process in collaboration with Chartered Semiconductor, based in Singapore. This process is based on through-silicon-vias (TSVs) and face-to-face bonding of copper pads on the surface of two wafers. After bonding two wafers, one wafer is thinned to expose insulated tungsten posts or TSVs, buried 6 microns deep in the bulk silicon at the silicon foundry, and topside metallization is then deposited by Tezzaron. This process can be repeated for multiple layers. Given the large reticule size in the Chartered process, Fermilab offered to organize a 3D multi-project wafer (MWP) run in this process for the worldwide high-energy physics community. As a result, 16 institutions from Italy, France, Germany, Poland, and the U.S. have contributed to the first MPW run. The first MPW run has two tiers of electronics built in the Chartered 130 nm CMOS process. The run was closed in June 2009 but production was delayed due to numerous issues related to the fact that this was the first 3D MPW run ever, which included more than 25 designs from many participating institutions. Included in the run are designs for Super-CMS trigger/tracker strip-pixels, Super-ATLAS pixels, ILC pixels, B factory pixels, x-ray imaging pixels, as well as various test circuits. Besides numerous test structures, Fermilab has contributed three large designs for the Tezzaron/Chartered run:

> VICTR: The VICTR chip is designed to demonstrate the application of 3D technology to the formation of a track-trigger for CMS at the SLHC. The track-trigger concept is based on a momentum filter utilizing a pair of silicon sensors separated by ~1mm and interconnected vertically, allowing local processing of hit information. This concept is the basis of a recent R&D proposal to CMS by 10 US institutions. The R&D proposal also includes R&D on interconnections, simulation, system design, and testing. The chip itself includes amplifier/discriminators, coincidence circuits, and a digital latch/shift register. The top tier of the 3D chip is intended to mate to a sensor with long strips to provide phi information, and the bottom tier is intended to mate with a sensor with short strips to provide z information. One major goal is to demonstrate the assembly of a sensor/chip/interposer/sensor stack based on 3D technology and bump bonding.
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> VIP2b: This chip is based on the three-tier VIP1 and 2a designs built in the MIT-LL 180 nm SOI process. The VIP2b is a two tier CMOS version of earlier designs that were designed as a demonstrator chip for an ILC vertex detector. The VIP2b is a much larger chip with a 192 x 192 array of 24-micron pixels. It has an 8-bit digital time stamp to provide 3.9 usec resolution time stamping. The CMOS version is expected to have better radiation tolerance and yield than the devices fabricated in the MIT-LL process.
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> VIPIC: This is a photon imaging chip designed in collaboration with Brookhaven National Laboratory and intended for x-ray photon correlation spectroscopy (XPCS). The chip operates in a deadtime-less fashion to record the arrival time of each photon in each pixel. In the VIPIC chip, the top tier is bonded to a sensor and handles the low-noise analog functions, and the bottom tier handles the digital event recording and time-stamping. The chip includes a 64 x 64 array of 80-micron pixels with a high speed sparsified data readout. The chip is adaptable to 4 side buttable X-ray detector arrays.

Our activities have led recently to a discussion between a consortium of IC fabrication services, MOSIS (USA), CMC (Canada), and CMP (Europe), and Tezzaron and Fermilab with the intention of offering 3D processes to the IC community beyond HEP. This commercialization of the 3D multi-project run pioneered by Fermilab would be a significant advance in the development and application of 3D integrated circuits.

SOI: A variant on the 3D theme is the Silicon On Insulator (SOI) technology. SOI wafers typically consist of a thin (20 nm) silicon "device" layer, a 200 nm silicon oxide layer (the "insulator") and a thick "handle" wafer used for mechanical support. The handle wafer can be made of high resistivity silicon – raising the prospect of a truly monolithic integration of detector and readout. Development of SOI technology depends on collaboration with the silicon foundries. We have been working with two vendors, OKI (through KEK) and SVTC (through American Semiconductor).

We have collaborated very actively with KEK in their MPW runs with OKI Industries and have pursued designs of pixel detectors with complete in-pixel processing chains for imaging, and some tests structures to explore the properties of the available process. Two generations of Monolithic Active Matrix with Binary Counters (MAMBO) ASICs were submitted on runs in 2006 and 2008. The target of the MAMBO is detection of radiation of single particles, like electrons in electron microscopy, or in tracking, or low energy X-Rays up to 12keV. Detailed tests led to the conclusions that the process has problems related to direct capacitive coupling between the detector and electronics. The prototypes allowed assessment of the correct functionality of the processing electronics and detection of signals originating from conversions of low-energy X-rays in the bulk. Our ideas on process changes have been accepted by the foundry and will be included in the submission for MAMBO III.

> MAMBO I: The MAMBO-I chip was our first attempt to use SOI technology to integrate readout electronics and detectors in a monolithic device. The MAMBO is an imaging chip, aimed at x-ray and electron microscope focal plane applications. It consists of an array of p-on-n pixels integrated into the handle wafer of an SOI stack and associated readout electronics fabricated in the top 20 nm silicon layer. We have verified the operation of the basic components of the MAMBO and verified charge collection with high gain (low load capacitance) from the diodes. The device, however, suffers from substantial "backgate" effects.
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> MAMBO-II: The MAMBO-II chip addressed some of the features observed with the first chip. Many additional structures were implemented that allowed detailed characterization of the process. It was observed, however, that there is adverse influence on the detector and the CMOS circuitry, again caused by the "backgate" effect. The current process of fully depleted SOI does not lend itself to the design of precise analog circuits.
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> MAMBO-III: The MAMBO-III chip serves a dual purpose. With the introduction of nested wells (buried p- and n-wells), recently agreed upon by the foundry, an efficient shielding of the detector and electronics will become available with this new process. Furthermore, the device was divided into two tiers. The top tier comprises the electronics and the bottom tier consists of an array of detector diodes which addresses some of the features observed with the first chips. The subdivision into two tiers allows exploration of the Au/In + adhesive underfill 3D bonding process offered by T-Micro (formerly ZyCube). The 3D bonding is supported through US-JAPAN funds.

We have participated in two Small Business Innovation Research (SBIR) grant proposals with American Semiconductor Industry (ASI), aimed at providing an alternate SOI-based detector technology. The ASI technology is based on their proprietary "FLEXFET" transistor, which has both top and bottom gates. The bottom gate acts as a shield which can reduce or eliminate both backgate and radiation effects. In our most recent SBIR we collaborated on the design and fabrication of a diode array on a high resistivity (1 KΩ-cm) handle wafer. In collaboration with Cornell University we have completed the process of thinning, backside implantation, and laser annealing of these devices. Tests of parts thinned to 50 microns both with a probe station and SVX4-based readout have confirmed good charge collection, low leakage current, and full depletion voltage of about 6V, consistent with the starting resistivity. The wafers include sensors, which will be mated to the MIT-LL VIP2a chips for testing. We note that this process will allow for detectors to be fabricated on full 8" wafers (rather than the current limit of 6" for most silicon detector vendors), in a process which provides excellent surface planarity which allows direct application to a Ziptronix-like oxide bonding process.

Bonding Technologies: 3D-related technologies provide a path to high performance integration of sensors with readout electronics. However, the bonding of sensors to readout electronics at ultra-fine pitch at reasonable cost was an unresolved problem. The Fermilab pixel group has explored two bonding technologies to address this issue.

A very promising technology is the Direct Bond Interconnect (DBI) technology from Ziptronix, based on oxide bonding of wafers and chips with embedded metal to form the inter-layer contact. This technology can achieve a pitch of 3 microns or less, and allows for aggressive thinning, and can be used with wafers or individual die. Die can be placed with standard pick-and-place machines at room temperature, eliminating the multiple thermal cycles necessary for multi-chip solder bumping. The DBI technology can also be used in conjunction with the embedded through-silicon-vias available in the Tezzaron/Chartered technology to assemble a large area detector array that can be tiled with chips and contacted through the backside. Our initial work established the viability of the technology by utilizing BTeV readout wafers and sensor wafers from MIT-LL. Sensor wafers were diced and those die were placed on the BTeV wafer. The sensors were then thinned from 300 to 100 microns. We found that devices with no bond voids (about 60% of the devices) had all pixels connected, showed low noise, and had no evidence of IC-sensor crosstalk.

Over the last year we have worked with Ziptronix and Brookhaven National Laboratory to design the additional metal layers, which will allow the Tezzaron wafers to be DBI bonded to sensors. We are planning to use the "seed" metal layer to redistibute the IC bond pads, which will be face down, to the surface of the sensor.

A relatively conventional bump bonding technology was also pursued with RTI to demonstrate the feasibility of bonding at a pitch less than 20 microns. Two processes were studied: CuSn bonded to Cu and SnPb bonded to Ni/Au. The bond yield of the CuSn bonding was in excess of 99.995% with bumps of about 10 micron diameter, thus establishing the feasibility of CuSn bonding for fine pitch assembly of 3D circuits.

We are collaborating with KEK in the 3D integration of an SOI detector/readout stack using the T-Micro process, mentioned earlier. This is an indium microbump-based process. The bottom layer is used as a detector and the top layer, which is now isolated from the backgate, contains the active circuitry.

A copper-based chip-to wafer process is also being developed by Tezzaron to supplement their wafer-to-wafer process. This is another promising development, which may provide the best yield for large area devices.

Sensors: Thinned sensors are interesting for a number of reasons. Thinning to 50-75 microns is the only way to achieve the material budget goals for a lepton collider vertex detector. Thinned detectors are also intrinsically radiation hard because the depletion voltage scales as the square of the thickness. A thinner detector can be fully depleted at lower applied voltage. Initial charge collection is lower, but thinned detectors have demonstrated equal or higher collected charge after the trapping distance becomes smaller than the detector thickness. However, foundries require wafer thicknesses between 300 and 700 microns for safe handling. Thinning after processing requires formation of a new backside Ohmic contact, which typically requires a high temperature anneal which destroys topside metallization. In collaboration with Cornell University we have developed a thinning and laser-based annealing process that can produce a high quality Ohmic junction on a thinned wafer bonded to a pyrex handle wafer. The laser produces local heating of the implanted region of the silicon, preserving the top surface. This process has been used for sensors from MIT-LL, OKI and American Semiconductor.

We have also fabricated silicon sensors at MIT-LL. The sensors are fabricated with a "deep trench" technology that makes the sensor active to the edge. This allows for the construction of fully active, 4-side buttable devices. This, combined with oxide bonding, thinning, and laser annealing technologies can provide large area fully active sensor arrays for HEP, Astronomy, x-ray imaging and commercial applications. The MIT-LL sensors have been mated with the BTeV readout chips, as described in the previous paragraph on bonding technologies.

We are also collaborating with Brookhaven National Laboratory in the design and fabrication of sensors intended to mate to the VICTR, VIPIC, and VIP2b chips. The strict topology requirements of the Ziptronic process require special sensor processing with thin metal and oxide layers. The sensors were designed and laid out at Fermilab and are being fabricated at Brookhaven. A pre-production set of wafers to allow measurements of warp and topology should be available in July 2010.

Mechanical Supports: During the past three years, Fermilab has developed mechanical support structures for silicon tracker, silicon vertex detector, and test beam applications. This work, led by Bill Cooper, is carried out within the Fermilab pixel group, with mechanical engineering support from Kurt Krempetz. The design development included integration with other detector elements, such as the surrounding calorimetry, beam tube, and beam monitoring elements, of a larger detector. Designs were tailored to sLHC upgrades and future linear collider experiments. The need for precise, low-mass structures in such experiments leads to designs which extend the state-of-the-art and include features with far more wide-ranging applicability.

The majority of silicon support structures we have designed relied upon carbon fiber laminate material. Accordingly, the investigation of material thermal and structural properties relative to those of silicon was crucial. The requirement for stability with low-mass has led to minimalistic designs in which every piece of material serves a specific purpose and advantage is taken of geometric properties to maximize structural stiffness.

To date, the fabrication of prototypes and test samples and studies of constants of thermal expansion and mechanical properties have been a joint, cooperative effort between university groups and Fermilab. Beginning in 2006, those joint efforts included strong participation by the University of Washington, SLAC, groups in the UK (RAL, Bristol, Oxford, Liverpool, etc.), and groups in continental Europe and Japan. More recently, efforts have shifted to structures for sLHC upgrades and studies compatible with generic designs. In particular, we have been developing module mechanical structures for a silicon track-trigger of the CMS upgrade and overall support structures for modules, in coordination with groups from CERN and US university groups, including groups at Purdue, Rochester, Cornell, and UCDavis.

Power: The pulsed powering envisioned for the ILC (and likely the muon collider) allows the detectors to use low average power. However, this is at the expense of large instantaneous currents when the power is turned on. This, in turn implies massive cables if power is supplied near the ~1V operating voltage of modern electronics. The upgraded LHC experiments, with increased granularity and higher complexity of the front-end electronics, will require even more power than the present detector systems. A further increase of the material budget due to cables and cooling is not acceptable, both from an economic point as well as from the limited space available to put the cables. The two major alternatives are DC-DC conversion and serial powering. In Serial Powering a constant current is distributed through the whole detector and converted into an appropriate voltage at each module.

In collaboration with Rutherford Laboratory and the University of Pennsylvania, Marcel Trimpl has designed a demonstrator chip for serial powering, the SPI (Serial Powering Interface), which has been fabricated in 2008 using TSMC 250nm process and radiation tolerant design techniques. The chip is foreseen to act as a power management device on a module level. It provides a wide range of voltage supplies from 1.2 to 3V. The chip is fully functional. Moreover, the chip is able to withstand currents up to 4A, which is higher than specified and enough to cover the present upgrade specifications of sLHC modules.

Calorimetry

Dual Readout Calorimetry: Hadron calorimeters are expected to play a major role in the experiments at future lepton colliders. On one hand a relative simplicity of the final states will permit much more precise reconstruction of a hadronic jet; on the other hand it is expected that jet/W/Z spectroscopy may play a crucial role in the understanding of the spectrum and decay chains of new heavy particles in a manner similar to photon spectroscopy in nuclear physics or in the studies of charmonium.

R&D studies of hadron calorimetry were initiated in 2006 within the context of ILC-oriented detector development and are led by Adam Para, supported by Marcel Demarteau, Gene Fisk and Anatoly Ronzhin. The studies focused initially on the understanding of the physical limitations of the Particle Flow Algorithm, on the studies of local particle densities in the hadron calorimeter and on a possible design of the setup for the experimental demonstration of the performance of PFA-based calorimetry. Subsequent efforts focused on the potential of high-resolution calorimeters exploiting a dual readout technique. A flexible simulation of an optical calorimeter was developed within the SiD SLIC framework. It extended the simulation capabilities to a full range of optical processes and enabled different physical signals (for example scintillation and Cherenkov light) to be recorded and analyzed within a single active volume of the detector. The initial phase of the studies, conducted in collaboration with the University of Washington and Pisa University, focused on a design and performance of a planar calorimeter with interleaved scintillation and Cherenkov detectors. The results were presented at various meetings and demonstrated that the sampling fluctuations are responsible for a large fraction of the resulting energy resolution, hence indicating the advantages of the total absorption hadron calorimetry (TAHCAL).

Initial engineering studies have demonstrated that crystal-based hadron calorimeter is quite feasible and it can be almost seamlessly incorporated into a mature detector design. More complete studies of the physics principles of the TAHCAL and its implementation in the SiD detector were carried out and have demonstrated that the TAHCAL offers an interesting possibility of achieving superior energy resolution of the order of 20%/√(E) for hadronic jets and 12-12%/ √(E) for single hadrons. The resulting detector response is to a good approximation Gaussian, with no long tails in either direction. The energy resolution improves with energy like 1/√(E) with no indication of developing a constant term up to the energies of ~1 TeV. It is very likely that in practice the calorimeter response will be degraded by the leakage fluctuations, inevitable in any realistic detector constrained by the outer superconducting coil. It should be noted that heavy scintillating crystals read out with compact silicon-based photo detectors offer probably the calorimeter with the highest achievable thickness, in terms of the interaction length, of all available technologies, thus keeping the leakage at the achievable minimum. A design of a total absorption dual readout calorimeter was included as an option in the SiD Letter of Intent.

Pixelated Photon Detectors: A Pixelated Photon Detector, also called a silicon photomultiplier (SiPM), multi-pixel photon counter (MPPC), or Geiger-mode Avalanche Photo Diode, is a solid-state photo-detector with unique properties. It is insensitive to magnetic fields, has high gain and quantum efficiency, and has good photo-electron separation and excellent timing performance. The R&D on SiPMs at Fermilab is carried out by Gene Fisk, Adam Para and Anatoly Ronzhin. During the last two years we have constructed an experimental setup for the detailed characterization of these photo-detectors and have carried out studies of their performance as a function of different operating conditions. The studies were conducted in close collaboration with Northern Illinois University, LAL Orsay, and the University of Udine, as well as with several vendors of the photo-detectors. Devices from different manufacturers have been tested Studies of the temperature dependence of the performance of the Hamamatsu MPPC's were presented at the IEEE Conference in October 2008 and at the LCWS in November 2008 in Chicago.

We have studied the timing properties of SiPMs. By using a pico-second laser setup, with wavelengths of 405 and 635 nm, we studied the single photo-electron time resolution of these devices. A resolution of approximately one hundred picoseconds was obtained for the Hamamatsu MPPCs. The studies revealed that the resolution improves with applied bias voltage and depends on the wavelength of the light. Furthermore, the requirements on temperature and bias voltage stability to maintain pico-second timing resolution were investigated. These studies enabled the fabrication of a time-of-flight (TOF) system with quartz Cherenkov radiators, read out with Hamamatsu MPPCs. The TOF system has been integrated as part of the instrumentation of the Fermilab test beam and obtains a timing resolution of 35 picoseconds, which allows for tagging and momentum measurement of protons up to energies of ~10 GeV.

We have also studied the feasibility of using scintillator strips, read out with MPPCs, to detect muons. Tests were carried out with MPPCs, with readout by multi-anode photo-multiplier vacuum tubes as reference. Fermilab has developed a fast four-channel digitizer board to measure the optical signals. These boards, upon receipt of a trigger pulse, initiate a fast digitization (12bits) every 4 ns for the high bandwidth ADC. This board was developed to facilitate future larger scale tests. Results were presented at conferences on calorimetry and colleagues have expressed an interest in obtaining these digitizer boards from us for their own studies.

Research on pixilated photon detectors also includes a collaborative effort with university researchers working on CMS. There are plans to upgrade the CMS hadron calorimeter (HCAL) by using SiPMs. We are working with CMS by sharing results of various studies so that these can be used to help in the design of an upgraded HCAL system

Scintillator

Plastic Scintillator: The FNAL/NICADD Extrusion Line has produced plastic scintillator for experiments such as MINERvA (FNAL), T2K (USA, Japan and UK groups), Maya Pyramid Tomography (Sandia Laboratories) and Double Chooz (University of Chicago). It is currently in a development phase with other experiments such as Pierre Auger (FNAL) and the Hall B detector at Jefferson Laboratory.

Plastic scintillator R&D, carried out by Anna Pla-Dalmau and Alan Bross, has focused on using extrusion techniques as a means to distribute insoluble powders such as inorganic oxides and halides into polystyrene to improve scintillator sensitivity to neutrons and high energy γ-rays. In order to maintain the clarity of the scintillator, the particle size of these powders must be in the range of nanometers. Initial tests have been carried out with powders in the range of microns.

In the last three years we have focused on two main R&D efforts: (1) co-extrusion of fiber/scintillator and (2) modification of plastic scintillator for use in neutron detection and γ-rays. This generic R&D has progressed very slowly in both areas due to lack of funding.

For the first of these R&D efforts, the idea is to use fiber/scintillator co-extrusion to simplify the assembly process by extruding the scintillator around the wavelength shifting (WLS) fiber. Initial work in this area was dedicated to identifying a die manufacturing company that was familiar with the requirements of this extrusion technique. A die manufacturer was selected to produce a “test” die that would be able to produce a scintillator extrusion with a hole in the middle for the WLS fiber. The die was tested and is still in the tuning stages to meet specifications.

For the second R&D effort on high-Z plastic scintillators and neutron-sensitive plastic scintillators, we began by looking for commercially available compounds with a refractive index close to that of polystyrene and with particle sizes in the range of nanometers. Since the particle-size requirement was difficult to satisfy, we have performed an initial test using barium fluoride

(BaF_2) with micron-sized particles. This test yielded promising results, but the samples did not have acceptable clarity.

For the research on neutron-sensitive plastic scintillator, we have established an agreement with a company to investigate the preparation of a lithium salt using their patented process that yields nanometer-scale powders. The lithium salt is delivered in an oil medium to prevent agglomeration of the particles and requires specialized equipment to feed the material into an extruder. We have also purchased titanium dioxide powders prepared in a similar manner from the same company. The next step in this R&D effort is to perform tests using the lithium salt.

Muon Collider

In the next decade the physics of the Terascale will be explored at the LHC. Furthermore, planned experiments studying neutrino oscillations, quark/lepton flavor physics, and rare processes may also provide insight into new physics at the Terascale and beyond. This new physics might be new gauge bosons, additional fermion generations or fundamental scalars. It might be SUSY or new dynamics or even extra dimensions. In any case, it is hard to imagine a scenario in which a multi-TeV lepton collider would not be required to fully explore the new physics. A multi-TeV Muon Collider provides an alternative possibility for studying the details of Terascale physics after the initial running of the LHC. Recently a proposal for Muon Accelerator R&D has been submitted. This study needs to be complemented with a study of the physics and detectors at a Muon Collider. The goal of these studies is to understand the required Muon Collider parameters (in particular luminosity and energy) and map out, as a function of these parameters, the associated physics potential. The physics studies will set benchmarks for various new physics scenarios (e.g., SUSY, Extra Dimensions, New Strong Dynamics) as well as Standard Model processes. The development of the physics case will be coordinated with the design of the detectors and their performance, the design of the interaction region, and studies of the background environment. This coordination will be required to determine the signal efficiencies and background rates. We propose to capture the physics and detector study for a Muon Collider under the KA12 budget line.

The latest, most complete study of the physics and detectors at a Muon Collider is the 1996 Snowmass study. One of the main conclusions of that study was that the environment at a Muon Collider, though hostile, was not prohibitive. Since then a lot of progress has been made both in the area of detector development and lattice design for the Muon Collider. We are proposing to initiate a renewed Muon Collider physics and detector study. Not much new work has been done since we proposed to have a new, updated look at the Muon Collider physics and detector program. Fermilab has hosted a workshop on the Machine – Detector – Physics program at a Muon Collider from November 10-12, 2009. The status of the work to date was reviewed and some new results were reported. One of the most critical aspects of a Muon Collider is the backgrounds. Muon beam parameters considered so far are as follows: $E = 0.75$ TeV, $\varepsilon_{\perp N} = 25\ \pi\cdot$mm$\cdot$mrad, $\sigma_p/p = 0.1\%$ and the inner radius of magnets closest to the interaction point (IP) is determined by the requirement $R > 5\sigma_{max}+1$ cm. The current lattice design includes dipoles placed immediately after the final focus doublet, generating a sufficiently large dispersion function at the location of the sextupoles nearest to the IP to compensate vertical chromaticity. A ±250-m segment of the lattice was implemented into the MARS15 model with conventional quadrupoles and open-midplane dipoles. The model includes rather detailed magnet geometry, materials, magnetic field maps, tunnel, soil outside and a simplified experimental hall plugged with a concrete wall, with and without tungsten masks in the magnet interconnect regions. It also includes a modified ILC detector model, taken to be the 4th detector concept, with B_z=3.5 T. Cutoff energies are optimized for materials and particle types, varying from 2 GeV at ≥100 m to 0.025 eV in the detector.

Due to a very high energy flux of electrons and photons in the large aperture, the whole triplet is a source of backgrounds in the detector. As calculated, electron and photon fluxes and energy deposition density in detector components are well beyond current technological capabilities if one applies no measures to bring these levels down. It has been found in earlier studies that the most efficient way to protect the tracker and other central detectors is a limiting aperture very close to the IP, with an interior conical surface which opens outward as it approaches the IP. These collimators have the aspect of two nozzles spraying electromagnetic showers at each other, with the charged component of the showers being confined radially by the solenoidal magnetic field and the photons from one nozzle being trapped (to whichever degree possible) by the conical opening in the opposing nozzle. Careful optimization is required to provide an adequate protection while not sacrificing the physics. In the current design, the collimators start at ±6cm from the IP with R=1 cm at this location and continues up to the first quadrupole at 6m. The collimators are made of tungsten, encapsulated in a borated poly shell, with the outer cone angle varying from 6 to 20 degrees. The tunnel is plugged with massive shielding at the entrance to the experimental hall, with additional copper/poly shielding in the endcap calorimeter region. Studies to date show that background levels in the detector components can be reduced by up to three orders of magnitude compared to the original background studies. Simultaneously, the files have been generated of particles entering detector components, which can be used as a source term by the detector community.

Our current approach to answering questions about the beam backgrounds is to rely on MARS simulations. The MARS simulation has a design for the accelerator elements and the delivery of the beam to the impact point of collisions, as described above. The MARS team has been provided with a description of the geometry of a detector, based on the specifications of the SiD detector developed for the ILC. We have begun to investigate the properties of these beam backgrounds. In general, the beam backgrounds fall into the following classes: low energy particles < 0.1 GeV with large statistical weight and high energy particles (> .1 GeV) with smaller weights. The strategy is to treat the low energy component as a continuum whose fluency determines which regions of the detector can be instrumented, and the degradation to instrumentation due to the background flux. The high energy component will be sampled statistically to determine which beam backgrounds to overlay on an event-by-event basis. Already, the studies of MARS output have provided useful information: a significant flux of particles appears at a large radius from the beam pipe and at a significant z displacement from the interaction point. This means that the detector simulation must be able to deal with particles arising from arbitrary location.

In 2009 and early 2010, a series of MARS files were used in a full simulation of the 4th detector concept design. Over the course of this short period, the interaction region model in MARS has been substantially improved especially in the region ± 20−30 meters from the IP. It now includes realistic quadrupole and dipole models, with optimized Tungsten masks in every interconnect region between IR optics elements. Also, the shielding cone has been optimized both inside and outside.

III. Research Plan

The targeted R&D program on new detector technologies that was initiated over the course of the last three years has received significant traction within the community at large. We would like to further expand on our detector R&D program. In addition we plan on expanding our effort to address the physics issues for a Muon Collider. The objectives of these studies are to provide a physics justification for a muon collider in the 1.5-5 TeV energy range, while making allowances for the expected results from the extensive running of the LHC.

There are many synergies among our R&D work for generic, ILC, sLHC and the muon collider. The muon collider detector will require radiation hardness similar to the sLHC with low mass sensors being developed for the ILC. A doublet module designed to reject low momentum tracks for an sLHC track trigger is remarkably similar to a module proposed by Steve Geer in 1996 for tracking in the high background environment of a muon collider. Techniques for power distribution, precision calorimetry, and low mass mechanical support are likely to be directly applicable in a muon collider environment.

Silicon

3D Integration: Our first 3D integrated circuits with Tezzaron were submitted at the end of June 2009. Three Fermilab full circuit designs and numerous test structures have been included in the submission. The research plan of the Fermilab pixel group calls for a full characterization of these devices, including basic analog and digital functionality, comparison of bonded (3D) and unbonded (2D) wafers and the evaluation of test structures. These tests will be completed in FY10. After completing these bench tests, the devices will be mated with sensors, fabricated at Brookhaven, using the DBI technology. We expect this to be completed in the first half of FY11. These full modules will then be bench tested during the second half of FY11. In FY11 the modules will also be tested in the Fermilab test beam. Bench tests of the bonded modules include studies of overall functionality, infrared laser scans, and studies with x-ray sources. Of particular interest will be the capacitive load associated with the small sensor to readout IC spacing, effects of noise shielding layers included in some of the sensors, and overall connectivity of the DBI bonded devices.

Given the success of our nascent 3D collaboration, we expect to prepare our second submission after testing the devices from the first run. Due to time constraints, not all proposed designs could be included in the first run. The second run is expected to occur early in 2010 with a third run later in the year. Several additional organizations have applied to join the consortium and contribute to the next runs. Second generation designs are expected to include chips designed to allow three or four side tiling to explore the feasibility of tiling large arrays with oxide bonded chips. This is a potentially transformational technology both for HEP designs and as well as for applications such as x-ray focal plane detectors and PET scanners. The second generation VICTR chips will be used to build “mini modules” with multiple chips placed on a host sensor to explore issues related to array fabrication. We expect to complete this work at the end of FY10, or early FY11. We also expect to utilize the third generation ILC VIP chip to build similar demonstration modules in FY11. Since production of these devices is done at large commercial companies, we are very optimistic about the success of this endeavor. We are planning to significantly increase the R&D effort, and work towards enabling this technology for physics experiments.

For the CMS upgrade we plan to add trigger functionality to the VICTR2. We are currently designing and modeling high bandwidth interconnects based on micropipline architectures which can transmit full event and trigger data in 25 ns. The space available in the current chips can be utilized to provide programmable trigger functionality as well as multi-event buffering. We expect that the next generation chips will allow us to begin to understand critical issues in system design such as yield, power consumption, latency, and hardware algorithm design.

We also expect to continue development of unique x-ray sensors in collaboration with BNL and Argonne. The VIPIC chip will be the first demonstration of a chip capable of time correlation x-ray spectroscopy. We expect to continue with these developments either expanding the capabilities or time resolution. We currently have two ASICs under development for application at light source facilities. One is a photon counting chip that could also be used for electron microscopy and the other is being developed for X-ray photon correlation spectroscopy. In addition, we expect to support Argonne in ASIC development for ILC related projects.

SOI: Our recent work with KEK/OKI has been very successful and has led to the adoption by the foundry of some of our suggested process changes. We plan on continuing this work. The recently submitted MAMBO III is designed to exploit both the 3D integration and the integrated detector in SOI technology. It should be mentioned that the 3D bonding is funded through the US-Japan fund. This device was divided into two tiers with the top tier comprising the electronics and the bottom tier consisting of an array of detector diodes. The T-Micro 3D integration process is used to bond the detector in the lower tier to the electronics in the upper tier. This separates the functions of charge generation and charge processing to two SOI layers. Thus, the direct coupling paths, which caused serious limitations, are now eliminated. The exploration of the T-Micro bonding that became available on the last run was seized upon as a very attractive opportunity to complete the portfolio of the explored 3D bonding processes at Fermilab in our focus of the 3D-IC development. The introduction of nested wells (BPW and BNW) has recently been agreed upon, thus efficient shielding of the detector and electronics will become available on the process. With the inclusion of nested wells, a successive submission of MAMBO IV is planned to again try to integrate the detector and electronics in a single tier. This will enable us to once again exploit the advantages of the SOI process with a monolithic combination of the detector and electronics, having eliminated its negative impacts. The submission of the MAMBO IV chip is planned on the next announced SOI MPW run in August 2010. Bench and beam testing of these devices will be carried out until well into FY11.

A Phase I SBIR with American Semiconductor has recently been approved. We will a contribute schematics of a MAMBO-like design for conversion by ASI into the “FLEXFET” process. This is a particularly interesting process, since it should be robust against backgate effects and radiation hard. However the process is not well developed and we need to gain confidence in the transistor models, understand the noise performance, and learn how to exploit the dual gate of the FLEXFET.

Bonding Technologies: In summer 2010 we plan to measure the topology and warp of the preproduction BNL sensors to confirm that they are suitable for bonding. A second round will then be fabricated for use in the DBI process. Ziptronix will receive the 3D two-tier wafers from Tezzaron, bond them to handle wafers and send them back to Tezzaron for exposure of the bottom through-silicon-vias. In late FY10 we will DBI bond the readout chips fabricated in the Chartered/Tezzaron 3D process to sensors fabricated at BNL, and expose the backside TSV contacts. Bench and beam tests will follow.

We believe that the Ziptronix DBI technology is extremely promising for applications in high-energy physics and could provide edgeless detector arrays and vertical connections suitable for the CMS SLHC trigger. DBI, however, is not the only relevant technology. In earlier work with RTI we have shown that Cu-Sn interconnects are also very promising. Similar thinning techniques can be used with these technologies. However, they are not as planar as the DBI process, so exposing the TSVs would have to be based on a combination of grinding and etching. We have recently learned of a Cu-Cu chip to wafer bonding process being developed by Tezzaron. This has the potential of low cost, high yield, and good synergy with our existing work with the company.

The next phase of the R&D will include exploration of building arrays of devices for ILC vertex detectors, CMS detectors, as well as x-ray focal planes. The 3D technology and associated TSVs provide the capability to fabricate large area, edgeless, tiled arrays with high speed readout. They also provide local provision of power and ground, which should enable high sensitivity, low noise devices.

We are also exploring similar technologies with other vendors. We have had initial discussions with Hamamatsu, which is also developing an oxide bonding technology. We intend to begin working with Hamamatsu, in collaboration with CERN, to develop an alternate implementation of TSV-based technology.

Sensors: We are in the process of fabricating sensors together with BNL for bonding 3D devices from the Tezzaron run. With the next run of Tezzaron, we expect to continue our collaboration with BNL producing sensors to mate with 3D devices that have no integrated detector.

The DBI process was developed to bond planarized wafers. Most HEP sensors have significant topology, which makes planarization difficult. We hope to work with Brown University, which has submitted an ADR to develop commercial post-processing planarization suitable for the DBI process. This would allow the Ziptronix or Tezzaron process to be used with sensors from almost any vendor. An alternative is to exploit our experience with ASI and OKI to pursue a detector technology based on 8" SOI wafers, which use a planar technology. A barrier to this is the reticule cost and size which would necessitate to the use of a so-called "stitching" technology.

Mechanical Supports: We plan to develop the necessary tooling and then fabricate and test prototype carbon fiber laminate structures suitable for barrel and disk layers of a silicon tracker with dimensions commensurate with those appropriate for future collider experiments; module, support, and cooling structures appropriate for a silicon-based track trigger; and novel structures satisfying the stability and radiation length requirements of future silicon-pixel-based vertex detectors. Successful completion of this work would require modest, but non-negligible, technician, drafting, and engineering support through Fermilab and good coordination with university and Fermilab groups developing advanced metrology techniques. Not only would structures be developed with generic applicability to future experiments, but also the skills and specialized techniques necessary for the design and fabrication of high-precision, low-mass structures would be further refined.

Power: The SPI chip is currently at use at RAL. The SPi (Serial Powering Interface) chip will be placed on the next ATLAS strip module to provide an alternative powering of the ATLAS ABCn chip. Also BNL has received chips to investigate protection schemes which handle module failures using the SPi and some external circuitry. Current plans at Fermilab include field tests with the current CMS pixel chip and to explore its usability towards the CMS pixel upgrade and perhaps beyond.

Calorimetry

Dual Readout Calorimetry: While the initial studies of TAHCAL are very promising the ultimate road to the real detector is likely to be a long one. Several serious challenges have to be met before this technology can be seriously considered for a detector. These challenges fall broadly into four categories:

- Development of suitable, affordable optical materials, a.k.a. crystals. To be a serious contender for the application for hadron calorimetry, the cost of these materials produced in large scale must not exceed $2/cc.
- Development of suitable photo-detectors and associated readout electronics
- Improved understanding of the performance of the TAHCAL and the associated problems of inter-calibrations and leakage correction
- Experimental demonstration of the good energy resolution of the TAHCAL in the Fermilab test beam

We propose the following R&D program focused on a goal of establishing the TAHCAL as a viable detector concept at a future lepton collider.

Design and industrial scale production of new scintillating crystals is nowadays possible, as evidenced by the example of the PWO4 crystals for CMS. Several possible candidates for the crystals specifically optimized for dual readout calorimetry have already been identified; they include for example the modified PW(Mo)O4 and BSO crystals. The principal challenge of the crystal-based solution is related to the production costs. An attractive alternative may involve heavy scintillating glasses produced in a continuous mode. Recent advances in nanotechnology may open a possibility of embedding the scintillating nanomolecules into the Cherenkov crystals or glass.

Fermilab is not equipped and has no intention to develop new optical materials. Instead, we are in the process of forming a collaborative effort with Caltech and LBNL. Caltech has a suitably equipped facility to characterize new crystals and has good ties with crystal manufacturers. Lawrence Berkeley Laboratory has a facility for discovering new scintillator materials. This facility enables a large number of new materials to be crystallized and quickly identified as potential candidate for growing larger crystals. Over the next several years we expect to engage these institutions in the search for the new materials and production of the samples. We also hope to engage the Crystal Clear Collaboration in this project and to take advantage of its huge body of experience and its close ties with the crystal growing industry.

Our main role will be to evaluate the new materials and experimentally demonstrate the separation of the Cherenkov and scintillation light components. Methods to evaluate the discriminative power of various techniques will be explored. Two methods that are currently being considered are wavelength filtering and analysis of the time structure of the optical signal. Methods of light collections to ensure adequate efficiency and uniformity of light collection are of course part and parcel of these studies. Special attention will be paid to optical coupling, wrapping and mirroring of the devices.

A critical aspect to the success of this technique is the development of a realistic, practical solution for photo-detectors, which offer adequate light collection efficiency with low noise. A promising candidate photo-detector is the Silicon-Photomultiplier. We have started to develop an ASIC, called SiPM Amplifier and Readout Chip (SPARC), which would be well suited to the readout of crystal calorimeters with SiPM based photo-detectors. It is anticipated that by the end of 2010 this project will have advanced enough to support a system of about 100 channels. The specifications of the chips are well suited to dual readout calorimetry with crystals, providing a very wide dynamic range, low noise, good timing resolution and input well matched to large area SiPM devices. This design will leverage both the experience with SiPMs and the long experience of the Fermilab ASIC design group with front-end readout chips.

Fermilab currently has the infrastructure to carry out studies of single crystals or glass samples using cosmic muons. Through these studies the performance of the different samples, in combination with different light collection and readout alternatives, can be characterized. The samples can be tested under a wide array of experimental conditions to optimize the devices for application of the dual readout technique to total absorption calorimetry. For example, the light collection efficiency will be studied for different particle trajectories through the crystals and samples will be equipped with various optical filters to study the capabilities of Cherenkov and scintillation light separation based on wavelength. Moreover, various photo-detectors will be cross-referenced.

In addition to single crystal studies, Fermilab plans an exposure of several electromagnetic crystal calorimeters to particle beams in the Fermilab Mtest facility. The initial set of studies will involve detailed studies of an electromagnetic calorimeter consisting of PbWO4 crystals. The second phase of the test beam studies, to occur on the time scale of about a year from now, will involve the construction and operation of segmented electromagnetic calorimeters constructed form different crystals, such as BGO, PbF2 and possibly other crystals or glasses determined to be suitable test candidates by the Caltech studies. The results of the initial phase of the studies will be used to design an improved method of separation of Cherenkov and scintillation light and to establish an adequate calibration procedure for both read channels. Comparison of the response and the energy resolution obtained with dual readout crystals, like BGO, with those obtained with pure Cherenkov radiator, like PbF2, will provide a test of the quality of the separation of the components of light. It is expected that the SPARC chip will be used for the readout.

The simulation studies for TAHCAL calorimetry will be continued in several areas: more detailed simulations including saturation effects, detector in homogeneities due to cracks and structural elements will be included, for example. We expect these studies to lead to a conceptual design of the crystal-based calorimeter, which can be implemented into a design of the complete detector. We will also develop a framework for more detailed studies of the shower development, including the time and spatial correlations between crystals. These studies will be essential in the design and optimization of the full-scale hadron calorimeter module to be tested in the Fermilab test beam.

Detailed simulation studies provide good understanding of the functioning of the total absorption calorimeter, but the ultimate proof must be provided by a construction and successful operation of a prototype of the detector. The test beam study program at FNAL will proceed in three phases:

- Studies of single crystals and various photo detectors. The aim will be to evaluate the light yield of the scintillation and Cherenkov components, evaluate the efficiency and purity of the separation of the components, development and test of the calibration and monitoring schemes.
- Studies of the ‘EM-size’ calorimeters. Segmented calorimeter equipped with various kinds of photo detectors will be used to check the accuracy of the relative calibration in the scintillation and Cherenkov modes.
- Design and construction of a full scale hadron calorimeter prototype.

Pixelated Photon Detectors: We plan to expand the SiPM characterization facility in FY10 and FY11 to study the detector response as function of wavelength, and install a track trigger that enables the study of light collection as function of incident position in the device under test. Our main effort will be directed towards the readout of the photo-detector, as described above.

Scintillator

Plastic Scintillator: For the next three years, the generic R&D for plastic scintillators will be led by Anna Pla-Dalmau, with participation from Alan Bross. The R&D will focus on three areas of interest. The first is the development of scintillator/fiber co-extrusion, since this will benefit future experiments that plan to use extruded plastic scintillator. The second is to pursue the preparation of high-Z and neutron-sensitive extruded plastic scintillator. There is interest in these types of scintillators in the nuclear physics community for experiments in the Spallation Neutron Source at Oak Ridge National Laboratory, and for the potential use of detecting nuclear materials for the U.S. Department of Homeland Security. The extrusion techniques that we are working on could lead to a significant reduction in cost and enable the production of large quantities of scintillator. The third area of interest is to investigate the use of an environmentally-friendly solvent for liquid scintillator applications.

Muon Collider

During the next 2–3 years the physics case of a Muon Collider will be refined and the physics reach as a function of energy and luminosity of the collider will be documented. This will enable the specification of the initial configuration parameters for the collider before the completion of Muon Collider design studies. It will be important to establish a software platform for the physics studies as early as possible and dedicated resources, both manpower and equipment, are needed. The physics case needs to have broad laboratory theory group involvement and support. The larger theory community also needs to be included in this effort.

One of the key issues is background mitigation and the development of a solid Machine-Detector Interface (MDI). Fermilab scientists are responsible for the MARS simulation code, and have much experience in using this code to study machine related backgrounds. Fermilab scientists are also responsible for designing the Muon Collider final focus optics and the associated radiation hard magnets. This expertise uniquely positions Fermilab to host the Muon Collider MDI studies, and to take responsibility for the generation of background files for Muon Collider physics and detector studies, and the associated shielding optimization studies. Indeed, supporting this scientific effort, and hence enabling the generation of the essential background files for physics studies, is a critical first step towards building a broader multi-institutional activity on Muon Collider detector studies.

On the accelerator side of the MDI, the activities that we anticipate will be supported in the next three years by MAP at Fermilab are:

- Address the 0.5-1 kW/m loss rate in superconducting magnets (dynamic heat load and quench stability) through the study of open-mid-plane dipoles with high-Z rods cooled at nitrogen temperature, optimized tungsten masks between IR magnets and inner liners inside magnets.
- Study of 10T open mid-plane versus conventional cos(θ) dipoles (split in ~3m long pieces with masks between and modest high-Z liners) to get acceptable field quality, handle the forces and enclose the beam dumps so that radiation is controlled in the tunnel.
- Evaluate alternative technologies for short IR quads: permanent high-gradient quads very close to IP, holmium/gadolinium liners in quads, novel adhesive-free approach. Explore higher gradient quadrupoles and determine if a lower beta star is feasible. If this is possible, evaluate whether to use the gain to raise the luminosity or reduce N, raise f and thus reduce the detector background.
- Design a ring for 3 TeV.
- Revisit beam scraping schemes for 0.75 and 1.5-TeV muon beams.

In addition to this MAP supported work, the proposed KA12 supported work would evaluate the impact of the machine design changes on detector backgrounds and performance, and also:

- Implement more realistic geometry and magnetic field map in the MARS model.
- Continue studies of the dependence of backgrounds on the opening angle of the shielding cones in the forward direction, and explore the possibility of partly instrumenting the shielding.

- Optimize magnet interconnect regions to reduce detector backgrounds.
- Explore if short 20-30 T solenoid(s) from the last bend to the IP (with gaps for the quadrupoles) would help mitigate backgrounds.
- For each design, determine how much shielding is needed inside the final quadrupoles.
- Investigate confinement of incoherent pairs with the detector for various cone designs.

These studies will encompass an optimization of detector backgrounds, and an evaluation of detector performance in the presence of the backgrounds. In particular, the detector response to physics signals in the presence of IP and machine backgrounds will be modeled and its effect on the physics signals will be studied.

The detectors that will record and measure the charged and neutral particles produced in collisions at a Muon Collider are quite challenging. They must operate in an environment that is very different from that of the ILC. Compared with hadronic interactions, lepton collisions generate events essentially free from backgrounds from underlying events and multiple interactions. They provide accurate knowledge of the center-of-mass energy, initial state helicity and charge, and produce all particle species democratically. Muon Collider detectors need not contend with extreme data rates. Indeed, most likely they can record events without the need for electronic pre-selection and thus without the biases such selection may introduce. The challenges for the detectors lie in the areas of precision, radiation hardness and background rejection due to the copious background from muon decays. To define the physics reach of the detector, a realistic simulation is needed, one that includes beamstrahlung, background from muon decays in flight, and a realistic evaluation of the bunch structure of the beams with time stamping. This would allow for realistic pattern recognition and track fitting of charged tracks. We foresee that setting up the simulation framework will take most of the effort in the first year. The simulation studies will be further refined and tools will be developed in the subsequent years to establish the physics reach.

Many of the interesting physics processes at a lepton collider appear in multi-jet final states, often accompanied by charged leptons or missing energy. The reconstruction of the invariant mass of two or more jets will provide an essential tool for identifying and distinguishing W, Z, H, and top particles, and for discovering new states or decay modes. Ideally, the di-jet mass resolution should be comparable to the natural decay widths of the parent particles, around a few GeV or less. Improving the jet energy resolution to 3–4% of the total jet energy, which is about a factor of two better than that achieved at LEP, will provide such di-jet mass resolution. Achieving such resolution represents a considerable technical challenge. The ILC and CLIC detectors emphasize "Particle Flow" to improve the jet energy resolution. Simulation studies indicate that, up to center-of-mass energies of 1 TeV, jet energy resolution of 3.5% can be retained in an e^+e^- environment. How the Particle Flow analysis performance evolves with increasing center-of-mass energy, the importance of different detector technologies, and the sensitivity to backgrounds are all unknown at this point. We anticipate that R&D on calorimetry suitable for a 3-TeV Muon Collider will be a key component of the detector R&D program. The evolution of the performance of Particle-Flow-based technologies with center-of-mass energy will need to be compared with the performance of alternative technologies, such as total absorption dual-readout calorimetry.

It is expected that all simulation will be carried out in close collaboration with other National Laboratories and universities and that the software infrastructure that has been developed for the ILC will be used.

In three years, we aim to have an equivalent of the CLIC study outlining the physics case for a Muon Collider. There should be a head-to-head comparison with CLIC for several physics benchmarks. Furthermore, there should have been several iterations on the detector design, based on feedback from the machine and experimental community, leading to a mature picture.

IV. Support and Infrastructure

Fermilab provides extensive support and infrastructure that enables the Electron Accelerator-based program. The program at Fermilab is engaged in research and development of the detector technologies for future lepton collider experiments. Engineers and technicians from the Particle Physics Division (PPD) bring a wide range of experience to the design of particle physics detectors. The Computing Division (CD) provides extensive support for detector simulations along with engineering support in the design of trigger and data acquisition systems.

Other organizational units of the laboratory provide support to the lepton collider efforts. Technical Division (TD) provides services through operation of the central machine and welding shops. Business Services Section (BSS) and Facilities Engineering Services Section (FESS) provide general support to the program through numerous services such as procurement.

Engineering and fabrication support for development of new detectors is primarily provided by the technical staff of the Particle Physics Division (PPD), which brings diverse experience in the design, construction, and operation of experiments. Mechanical engineering expertise includes design and operation of precision tracking detectors, cooling and gas systems, large mechanical structures and finite element analysis. Electronics engineering in PPD covers a broad range from analogue to digital signal processing and electronics infrastructure. There is a strong ASIC group that is crucial to the lepton collider program. PPD has several detector assembly centers that specialize in particular aspects of detector development. One of particular importance to this program is the Silicon Detector Facility. The Meson Test Beam Facility, operated jointly by PPD and Accelerator Division (AD) is critical to test new technologies.

The technical staff of the Computing Division (CD) provides expertise in the development of data acquisition and trigger systems along with support of critical software systems. CD provides support through maintenance of computing systems and widely used tools that facilitate documentation and communication.

The primary organization providing mechanical engineering for detectors at Fermilab is the PPD Mechanical Department. The departments engineers have years of experience in cryogenics, mechanical design, project engineering, magnet design, pressure/vacuum vessel design and project management. The mechanical engineers and designers work closely with specialized detector assembly groups on the design of precision detectors and associated assembly tooling. Extensive experience in the design of low mass structures for tracking detectors is being applied to design of structures of lepton collider trackers. The department's engineering analysis group has provided FEA and magnetic field analysis for SiD detector and the 4th concept detector. This includes much of the finite element work for the conceptual design of the SiD 5T Solenoid and the 4th Detector Superconducting Magnets.

Electronics engineering for detectors is provided by the CD Electronics Systems Engineering Department (CD/ESE) and the PPD Electronics Engineering Department (PPD/EED). Together, these departments provide engineering with a wide range of design expertise for particle physics experiments from the front-end to DAQ and trigger systems. The PPD/EED provides support to the program primarily through the work of the Microelectronics/ASIC group. The primary focus of the ASICS group in PPD is mixed analog-digital signal and radiation tolerant designs. The

ASIC designers have experience with numerous technologies including CMOS, SOI, and BiCMOS. This group has designed numerous successful ASICs including the Charge Integrator Encoder (QIE) that through many generations has been used for readout of calorimeters on KTeV, CDF, MINOS, and CMS. They have also designed readout chips for silicon strip and pixel detectors. Work for the lepton collider programs include development of sensors and readout devices for precision tracking detectors and readout electronics for Silicon Photomultipliers (SiPMs). The primary current focus of the group is development of 3D architectures. This has the potential to transform detector readout. The ASIC design effort is supported by board design both within PPD/EED and within CD/ESE. They also receive support from an ASIC testing group within PPD/EED. The microelectronics group has developed in-house ASIC testing capability for both packaged and wafer level parts.

There are a number of facilities within the Particle Physics Division whose focus is assembling and testing detector systems. These include 8000 ft^2 of clean rooms, a vacuum and cryogenics group, scintillator development facilities and thin film deposition. Most of these facilities are part of the Technical Centers Department and were primarily developed as part of programs to construct experiments. Of primary importance to this program is the Silicon Detector Facility (SiDet) which constructed the CDF and D0 Run 2 Silicon Strip detectors, the CMS forward pixel detector and now DECam CCD camera. The facility specializes in fine scale assembly of detector modules, micro-bonding and large scale assembly of complete silicon trackers. SiDet has been used by the R&D program to prototype mechanical assembly of low mass trackers. Bare wafers are diced and assembled including wire bonding to simulate real detector structures. They have tested dicing ultra-thin (<75μm) silicon to understand the challenges of handling this material. SiDet also provides support to R&D in the ASIC area with bonding capabilities. The flip-chip bonder has been used to for bonding the SPI 3D ASIC to pixel sensors for testing. This provides fast turnaround on prototype devices.

Test beams are crucial to many detector R&D projects including those supporting electron accelerator based research. The ability to test real life operations of a proposed device in a high energy particle beam can be of great benefit to the research team. The Fermilab test beam provides 120 GeV proton beam with an approximate 0.3% momentum spread and can be focused to a 7 mm RMS spot size in the user area. In addition to delivering primary protons, there are two targets on movable stages that can act as secondary beam production areas. The magnets downstream of those targets can then be tuned to deliver any secondary momentum from 0.5 GeV to 60 GeV.

There is a unique base of expertise at Fermilab for simulation of machine related detector backgrounds, which organizationally resides in the Accelerator Physics Center (APC). The APC is responsible for the development of the lattice for the muon collider and they work closely together with the energy depositions group. This group has developed the program suite MARS, a Monte Carlo code for inclusive and exclusive simulation of three-dimensional hadronic and electromagnetic cascades, muon, heavy-ion and low-energy neutron transport in accelerator, detector, spacecraft and shielding components in the energy range from a fraction of an eV up to 100 TeV. This is the leading tool in understanding sources of background at any facility. They are responsible for simulating the backgrounds at a Muon Collider. Close cooperation with this group will be critical to develop a detector design that can operate in the Muon Collider environment.

V. Broader Impact

Very significant progress has been made in our understanding of the interactions of elementary particles over the last forty years. The Standard Model of strong, weak and electromagnetic interactions initially developed in the 1970‘s has been a great success. It has withstood ever more precise experiments (LEP, B-factories, …) as well as the advances of the energy frontier at the Tevatron. The quark sector was complete with the discovery of the top quark at CDF/D0 in 1995, and the lepton sector was complete with the discovery of the tau-neutrino at DONUT in 2000.

The final element of the standard model is the Higgs boson. The couplings of this particle are determined but its mass is not set in the Standard Model. The existing indirect evidence and direct experimental bounds suggest a mass in the range 114-152 GeV. This assures exclusion or discovery either at the Tevatron or the LHC within the next five years. The prevailing theoretical view is that the standard model will not survive unaltered at the energy scales probed by the LHC (at center-of-mass energy of 14 TeV), and that new physics (SUSY, strong dynamics, Extra Dimensions, etc) will appear. Whatever the new physics, a new lepton collider will be required to study its details.

These successes have been made possible because of the availability of forefront accelerator facilities, together with the detectors to mine the data and unravel the secrets of nature. The better the instruments, the quicker and deeper nature can be probed. Physics demands experiments at the next generation facilities to be precision instruments with capabilities that need to exceed current day performance by large factors. Fermilab has realized the need for transformational new technologies and has targeted two high impact areas of current day high-energy physics experiments: silicon vertex and tracking technology and calorimetry. The silicon technology being pursued is the 3D vertically integrated, tiered structures. It simultaneously addresses issues such as material budget, power consumption, integrated edgeless detectors, while at the same time offering the potential to substantially increase the front-end processing logic. If this technology is proven to be a viable technology for particle detection, it could truly be a revolutionary technology with its applications limited by one’s imagination. The second area is calorimetry. The recent development of silicon based pixilated photon detectors, opens up the possibility to design finely segmented calorimeters. Hadron calorimetry, however, has always suffered from poor energy resolution. Total absorption hadron calorimetry, with separation of Cherenkov and scintillation light, has been shown through simulations to be able to improve on the energy resolution by at least a factor of two. A research and development program of dual readout calorimetry with integrated photo-detectors has been initiated. The development of new materials to enable dual readout as well as the functionality of the front-end electronics, such as waveform digitization and fast timing, is addressed simultaneously. Also here, applications could reach well beyond high-energy physics.

Given the long research and development cycle for a new HEP facility the focus on transformational new detector technologies seems appropriate. When the time arrives, we also need to be ready to decide among the options for the next energy frontier lepton collider. Any energy frontier machine after the LHC should have the capability of both precision study of the new physics observed at the LHC and extending the discovery reach for new physics. Lepton colliders able to operate at multi-TeV energies seem to offer an attractive candidate for such a machine. Much study has already been devoted to one such option: an electron linear collider. The ILC (with energy upgrades) is well studied and the CLIC approach is under active research. A second option is a Muon Collider. This option offers a number of potential advantages including compact size and a whole range of intensity frontier physics opportunities associated with the accelerator complex to produce the required intensity of muons. A prime spinoff could be a neutrino factory. Another spinoff could be a low energy Muon Collider, which would be a Higgs factory and allow the direct measurement of the Higgs width.

The Muon Collider option requires investments in basic research to prove the viability of the concept. To assess the physics potential as a function of energy and luminosity for a muon collider in the 1.5-4.0 TeV energy range it necessary to develop an MDI design that leads to acceptable levels of backgrounds in the detectors; develop a fast detector Monte Carlo that allows study of a variety of few physics processes and extract the physics from the backgrounds in the detector. This detector research proposal will allow the development of a set of physics benchmarks for detector performance that can be used as goals for later detailed detector designs and for comparison of the physics reach of a Muon Collider with the electron LC alternatives (ILC and CLIC). These studies will position the field to make an informed decision which course to follow once the LHC results lead the way.

VI. Personnel and Funding

Here we summarize the funding and effort requirements for the activities proposed for this budget category. All values shown in the tables are "burdened" with appropriate overhead rates both for effort and for M&S. For future years the labor costs are escalated by 4% annually to represent "then-year" dollars. Table 1 shows the actual funding for the scientific effort directed towards detector R&D. The entries for FY2010 are the actual values up to April 2010. Given the

DOE Support FY 2009 (Actual)						
Personnel Support from DOE:	**Lepton Collider**		**Other**		**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	8	2.29			**8**	**2.29**
Temporary PhD	1	0.25			**1**	**0.25**
Graduate Students					**0**	**0.00**
Engineer					**0**	**0.00**
Computing Professional					**0**	**0.00**
Technician					**0**	**0.00**
Administrative					**0**	**0.00**
TOTAL	9	2.54	0	0.00	**9**	**2.54**
DOE/HEP Funding (per activity):						
SWF (in $, include overhead)		$616,000				**$616,000**
M&S (in $, include overhead)		$46,440				**$46,440**
Travel (in $, include overhead)		$54,560				**$54,560**
TOTAL		**$717,000**		**$0**		**$717,000**

DOE Support FY 2010 (Actual)						
Personnel Support from DOE:	**Lepton Collider**		**Other**		**TOTAL**	
	No. heads	**FTE**	**No. heads**	**FTE**	**No. heads**	**FTE**
Permanent PhD	5	2.32			**5**	**2.32**
Temporary PhD	1	0.25			**1**	**0.25**
Graduate Students					**0**	**0.00**
Engineer					**0**	**0.00**
Computing Professional					**0**	**0.00**
Technician					**0**	**0.00**
Administrative					**0**	**0.00**
TOTAL	6	2.57	0	0.00	**6**	**2.57**
DOE/HEP Funding (per activity):						
SWF (in $, include overhead)		$667,000				**$667,000**
M&S (in $, include overhead)		$37,540				**$37,540**
Travel (in $, include overhead)		$51,160				**$51,160**
TOTAL		**$755,700**		**$0**		**$755,700**

Table 1: Scientific effort for FY09 and FY10 on detector R&D.

anticipated success of the current 3D silicon submission, we would like to request a modest increase in effort by adding one FTE of scientific staff to this activity. The devices that will be delivered late spring 2010 will have to be extensively bench tested followed by integration with sensors. These demonstrator devices will then be exposed to beam tests and irradiation studies. At the same time preparations need to be made for the next MPW 3D submission. Hence a strengthening of the effort is needed, which is reflected in Table 2. The M&S budget covers short-term guest scientists and general scientific support.

Table 2 lists our effort for the fiscal years 2011 through 2013. The column labeled ‘Other’ is our request for the Muon Collider physics and detector study. As described in the Research Plan section, the effort strongly focuses on simulations. Three areas of simulation are targeted. The first is the critical Machine-Detector-Interface where reliable estimates of the various sources of background need to be obtained, which will lead to a common understanding of the background levels as function of the design details, such as the shielding cone angle. The second area is the simulation of the detector response including all sources of background and physics processes. Both fast and full simulations will be performed. The third area is the simulation and full event reconstruction of physics benchmark processes. A computer professional whose effort ramps up from 30% to full-time will support the physicists with simulation expertise working on these issues. The M&S budget provides for the massive disk storage space that is foresee for these studies.

DOE Support FY 2011 (Proposed)						
Personnel Support from DOE:	Lepton Collider		Other		TOTAL	
	No. heads	FTE	No. heads	FTE	No. heads	FTE
Permanent PhD	7	3.10	5	2.00	**12**	**5.10**
Temporary PhD	1	0.25			**1**	**0.25**
Graduate Students					**0**	**0.00**
Engineer					**0**	**0.00**
Computing Professional			1	0.30	**1**	**0.30**
Technician					**0**	**0.00**
Administrative					**0**	**0.00**
TOTAL	8	3.35	6	2.30	**14**	**5.65**
DOE/HEP Funding (per activity):						
SWF (in $, include overhead)		$885,000		$625,000		**$1,510,000**
M&S (in $, include overhead)		$64,000		$70,000		**$134,000**
Travel (in $, include overhead)		$51,000		$15,000		**$66,000**
TOTAL		**$1,000,000**		**$710,000**		**$1,710,000**

DOE Support FY 2012 (Proposed)						
Personnel Support from DOE:	Lepton Collider		Other		TOTAL	
	No. heads	FTE	No. heads	FTE	No. heads	FTE
Permanent PhD	7	3.10	8	4.00	**15**	**7.10**
Temporary PhD	1	0.25			**1**	**0.25**
Graduate Students					**0**	**0.00**
Engineer					**0**	**0.00**
Computing Professional			1	0.50	**1**	**0.50**
Technician					**0**	**0.00**
Administrative					**0**	**0.00**
TOTAL	8	3.35	9	4.50	**17**	**7.85**
DOE/HEP Funding (per activity):						
SWF (in $, include overhead)		$910,000		$1,250,000		**$2,160,000**
M&S (in $, include overhead)		$65,000		$100,000		**$165,000**
Travel (in $, include overhead)		$52,000		$15,000		**$67,000**
TOTAL		**$1,027,000**		**$1,365,000**		**$2,392,000**

DOE Support FY 2013 (Proposed)						
Personnel Support from DOE:	Lepton Collider		Other		TOTAL	
	No. heads	FTE	No. heads	FTE	No. heads	FTE
Permanent PhD	7	3.10	10	5.00	**17**	**8.10**
Temporary PhD	1	0.25			**1**	**0.25**
Graduate Students					**0**	**0.00**
Engineer					**0**	**0.00**
Computing Professional			2	1.00	**2**	**1.00**
Technician					**0**	**0.00**
Administrative					**0**	**0.00**
TOTAL	8	3.35	12	6.00	**20**	**9.35**
DOE/HEP Funding (per activity):						
SWF (in $, include overhead)		$930,000		$1,715,000		**$2,645,000**
M&S (in $, include overhead)		$67,000		$130,000		**$197,000**
Travel (in $, include overhead)		$53,000		$15,000		**$68,000**
TOTAL		**$1,050,000**		**$1,860,000**		**$2,910,000**

Table 2: Funding request for FY11-13 for lepton collider R&D

VII. Summary

Lepton colliders are very attractive candidates for the next generation accelerator facility to precisely explore the areas of new physics that will have been opened up by the LHC. In 2006 Fermilab got involved in electron accelerator based research by starting an active participation in the design and physics studies of the SiD detector concept in the framework of the ILC. A detector R&D effort was started to develop new detector technologies that would address the physics needs of the ILC. Although the R&D was carried out in the framework of the ILC, new initiatives were carefully evaluated on their range of applicability and where possible, technologies were pursued that had the potential to be truly transformational and had a broad range of applicability. The initial emphasis was on the development of new silicon detectors with associated mechanical and electrical supports, calorimetry and the exploration of PPDs for use in particle detectors. After a careful evaluation of the various silicon technologies, Fermilab decided as the first institution in the field, to explore the vertically integrated, tiered, 3D silicon technology. The first-ever 3D silicon chip for readout of a silicon pixel detector in an ILC environment was obtained in 2008. The successful design included time stamping, token-ring readout and data sparsification. This device was obtained through collaboration with MIT-Lincoln Laboratories. A more reliable commercial path for the development of the 3D technology was explored and a local company Tezzaron was identified as one of the leaders in the 3D integration technology. A design submission through Tezzaron opened the possibility for a Multi Project Wafer run and we offered the high-energy physics community the option to participate in the MPW run. A consortium of 16 international institutions was formed that participates in the first-ever 3D MPW run, sponsored by Fermilab. 3D devices are expected to be available within a month as of the time of writing this report. Our success has not gone unnoticed by industry and have led recently to a discussion between a consortium of IC fabrication services, MOSIS (USA), CMC (Canada), and CMP (Europe), and Tezzaron and Fermilab with the intention of offering 3D processes to the IC community beyond HEP. This commercialization of the 3D multi-project run, pioneered by Fermilab, would be a significant advance in the development and application of 3D integrated circuits. The 3D technology holds the promise of being transformational and over the next years we would like to aggressively pursue this technology further. At the same time we have looked at alternative integrated technologies, such as the SOI technology, which receives active support through the US-Japan collaboration.

Total absorption dual readout hadronic calorimetry holds promise to improve on the hadronic energy resolution by a factor of two. A collaborative with universities and other labs has been developed for the characterization of new materials. All photo-detector work is now aimed at calorimetric applications. The ultimate goal is the integration of the photo-detector with the readout using the 3D silicon technology. A Muon Collider detector will be part of the scope for application of these technologies. To bring this R&D to the level of demonstrator devices we request an increase of the funding by 30%.

Recently a Muon Accelerator Plan (MAP) has been submitted to study the feasibility of a multi-TeV Muon Collider. A companion study needs to be carried out to assess if detectors can be built that will withstand the interaction region backgrounds and are sufficiently sensitive to pick out the physics with the required precision. We are proposing to initiate such a study under this budget category. The deliverable of this study, on a three-year timescale, will be a Physics and

Detector Conceptual Design Report. The main focus of these activities will be in three areas of simulation. The first is the Machine-Detector-Interface (MDI) where reliable estimates of the various sources of background need to be obtained that will feed into the Monte Carlo simulations. Files of backgrounds at specified MDI surfaces will be generated that can be used by the detector simulation group as a source term to establish a common understanding of the background levels to be expected as a function of the design details, such as the shielding cone angle. The second area is the simulation of the detector response including all sources of background and physics processes. A full realistic detector model for a Muon Collider detector will be developed. Simulations will be carried out through both a parametrized fast Monte Carlo and a full GEANT simulation with full event reconstruction. Existing simulation frameworks will be deployed. The third area is the simulation and full event reconstruction of physics benchmark processes. Special emphasis will be placed on the Since the machine most similar in performance is CLIC, a direct comparison of the physics reach of both facilities will be carried out. Studies will be done at center of mass energies of 1.5 TeV and 3 TeV.

Patents:

Patents derived from Fermilab detector R&D:

A. Bross, A. Pla-Dalmau, K. Mellot, Systems and methods for detecting nuclear radiation in the presence of backgrounds, **6,909,098**, June 21, 2005

A. Bross, A. Pla-Dalmau, K. Mellot, Systems and methods for detecting neutrons, **6,927,397**, August 9, 2005

A. Bross, A. Pla-Dalmau, K. Mellot, Systems and methods for detecting x-rays, **7,038,211**, May 2, 2006

A. Bross, A. Pla-Dalmau, K. Mellot, Extruded plastic scintillator including inorganic powders, **7,067,079**, June 27, 2006

Publications:

R. Yarema et al., “3D design activities at Fermilab - Opportunities for physics”, NIMA 617 (2010) 375-377

G. Deptuch, "Monolithic pixel detectors in a deep submicron SOI process", Nuclear Instruments and Methods in Physics Research Section A, In Press, ISSN 0168-9002, DOI:10.1016/j.nima.2010.02.189.

A. Ronzhin, M. Albrow, K. Byrum, M. Demarteau, S. Los, E. May, E. Ramberg, J. Vav'ra, A. Zatserklyaniy, “Tests of Timing Properties of Silicon Photomultipliers”, accepted by Nucl. Instr. and Meth. A (2010), doi:10.1016/j,nima.2010.02.072

A. Ronzhin, M. Albrow, M. Demarteau, S. Pronko, E. Ramberg, A. Zatserklyaniy, “Test of Timing Properties of the Photek 240 PMT”, FERMILAB-TM-2456E, submitted to NIM (2010)

Deptuch, G.; Demarteau, M.; Hoff, J.; Lipton, R.; Shenai, A.; Trimpl, M.; Yarema, R.; Zimmerman, T.; " Vertically integrated circuits at Fermilab", Nuclear Science Symposium Conference Record (NSS/MIC), 2009 IEEE (2009) 1907 – 1915

M. Trimpl, “The SPi chip as an integrated power management device for serial powering of future HEP experiments”, accepted at POS

R. Lipton, “3D Technology for Intelligent Trackers”, submitted to WIT2010 conference proceedings, Berkeley, February 3-5, 2010

M. Trimpl et al., “Demonstration of fine pitch Flip Chip on Board assembly based on solder bumps at Fermilab”, FERMILAB-TM-2447-E-PPD, JINST 4:T11001 (2009)

R. Lipton, “3D Detector and Electronics Integration Technologies: Applications to ILC, SLHC, and beyond”, submitted to “7th International "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors”, conference proceedings, Hiroshima, Japan, Aug. 29-Sep.1, 2009

J. Vav'ra, D.W.G. S. Leith, B. Ratcliff, E. Ramberg, M. Albrow, A. Ronzhin, C. Ertley, T. Natoly, E. May, K. Byrum, “Beam test of a Time-of-Flight detector prototype”, Nucl. Instr. and Meth. A 606, 404-409 (2009)

P. Luukka, J. Härkönen, T. Mäenpää, B. Betchart, S. Czellar, R. Demina, A. Furgeri, Y. Gotra, M. Frey, F. Hartmann, S. Korjenevski, M. J. Kortelainen, T. Lampen, B. Ledermann, V. Lemaitre, T. Liamsuwan, O. Militaru, H. Moilanen, H. J. Simonis, L. Spiegel “TCT and test beam results of irradiated magnetic Czochralski silicon (MCz-Si) detectors,” Nucl. Instrum. Meth. A 604, 254 (2009).

G. B. Cerati et al., “Radiation tolerance of the CMS forward pixel detector,” Nucl. Instrum.

Meth. A 600, 408 (2009).

W. E. Cooper, “Effects of Power Cycling on Vertex Detector Cables,” arXiv:0902.3023 (2009)

A. Ronzhin, M. Demarteau, S. Los and E. Ramberg, “Study of timing properties of silicon photomultipliers,” FERMILAB-CONF-09-055-E-PPD.

A. Ronzhin et al., “Testing a silicon photomultiplier time-of-flight (TOF) system in the Fermilab Test Beam Facility,” FERMILAB-CONF-09-062-E-PPD.

T. Abe et al. [ISS Detector Working Group], “Detectors and flux instrumentation for future neutrino facilities,” JINST 4, T05001 (2009) [arXiv:0712.4129 [physics.ins-det]].

Deptuch, G.; Christian, D.; Hoff, J.; Lipton, R.; Shenai, A.; Trimpl, M.; Yarema, R.; Zimmerman, T.; "A Vertically Integrated Pixel Readout Device for the Vertex Detector at the International Linear Collider", FERMILAB-PUB-08-564, IEEE Trans.Nucl.Sci.57:880-890 (2010)

J. Wu and Z. Shi, “The 10-ps wave union TDC: Improving FPGA TDC resolution beyond its cell delay,” FERMILAB-CONF-08-498-E.

R. Yarema et al., “3D IC Pixel Electronics - The Next Challenge,” FERMILAB-PUB-08-422-E.

V. N. Evdokimov and D. S. Denisov, “A study of a short-term instability and aging of FEU-115M photomultiplier tubes,” Instrum. Exp. Tech. 51, 89 (2008).

T. Mäenpää et al., “Silicon Beam Telescope For LHC Upgrade Tests,” Nucl. Instrum. Meth. A 593, 523 (2008).

V. Re, L. Gaioni, M. Manghisoni, L. Ratti, V. Speziali, G. Traversi and R. Yarema [Rad Hard Vertex Detector R&D - Pixels Collaboration], “Noise behavior of a 180-nm CMOS SOI technology for detector front-end electronics,” IEEE Trans. Nucl. Sci. 55, 2408 (2008).

A. Dyshkant et al., “MAPMT H7546B anode current response study for ILC SiD muon system prototype,” IEEE Trans. Nucl. Sci. 55, 1691 (2008).

A. Para, “Photodetectors for dual readout calorimetry”, Workshop on Trends in Photon Detectors for Particle Physics and Calorimetry, Trieste, Italy, June 4, 2008.

B. Bilki et al., “Calibration of a digital hadron calorimeter with muons,” JINST 3, P05001 (2008) [arXiv:0802.3398 [physics.ins-det]].

R. Abrams et al., “LC scintillator-based muon detector tail-catcher R&D,” In the Proceedings of 2007 International Linear Collider Workshop (LCWS07 and ILC07), Hamburg, Germany, 30 May - 3 Jun 2007.

J. Wu, S. Hansen and Z. Shi, "ADC and TDC implemented using FPGA," FERMILAB-CONF-07-601-E.

J. Krider and H. Nguyen, "A Temperature-Controlled Chamber Based On Vortex Cooling," FERMILAB-PUB-07-604-E.

J. Yu et al., "Roadmap for ILC Detector R&D Test Beams," FERMILAB-TM-2392.

U. Mavric and B. Chase [Linear Collider Collaboration], "Residual phase noise measurements of the input section in a receiver," FERMILAB-PUB-07-536-AD.

R. Yarema [Linear Collider Collaboration], "3D circuit integration for Vertex and other detectors," FERMILAB-PUB-07-625-E.

T. K. Kroc and A. J. Lennox, "Stability of A-150 plastic ionization chamber response over a 30 year period," Radiat. Prot. Dosim. 126, 623 (2007).

R. A. Rivera and M. A. Turqueti [PHENIX Collaboration], "The test stand system for the PHENIX iFVTX silicon detector," FERMILAB-CONF-07-098-CD.

D. Beznosko, A. Dyshkant, C. K. Jung, C. McGrew, A. Pla-Dalmau and V. Rykalin, "MRS photodiode coupling with extruded scintillator via Y7 and Y11 wls fibers," FERMILAB-FN-0796.

P. Balbuena et al. [RD50 Collaboration], "RD50 status report 2006: Radiation hard semiconductor devices for very high luminosity colliders," CERN-LHCC-RD-013.

M. Barbero et al. [RD42 Collaboration], "Development of diamond tracking detectors for high luminosity experiments at LHC," CERN-LHCC-RD-012.

S. Stanic et al., "Recent progress in the development of a monolithic active pixel detector for a B factory," Nucl. Instrum. Meth. A 579, 680 (2007).

R. Lipton, "3D-vertical integration of sensors and electronics," Nucl. Instrum. Meth. A 579, 690 (2007).

M. E. Dinardo et al., "First prototype of a silicon microstrip detector with the data-driven readout chip FSSR2 for a tracking-based trigger system," Nucl. Instrum. Meth. A 572, 388 (2007).

A. A. Moiseev, R. C. Hartman, T. E. Johnson, D. J. Thompson, P. L. Deering, T. R. Nebel and J. F. Ormes, "High efficiency plastic scintillator detector with wavelength-shifting fiber readout for the GLAST Large Area Telescope," Nucl. Instrum. Meth. A 583, 372 (2007).

J. Wu, M. Wang, E. Gottschalk and Z. Shi, "FPGA curved track fitters and a multiplierless fitter scheme," IEEE Trans. Nucl. Sci. 54, 1791 (2007).

R. Lipton, "ILC vertex detector issues and thoughts," Proceedings of VERTEX2007, 036 (2007).

H. Nakamura et al., "Multilayer Scintillator Responses For Mo Observatory Of Neutrino Experiment Studied Using A Prototype Detector Moon-1," J. Phys. Soc. Jap. 76, 114201 (2007) [arXiv:nucl-ex/0609008].

W. Adam et al. [RD42 Collaboration], "Development of diamond tracking detectors for high luminosity experiments at the LHC," CERN-LHCC-RD-010.

M. Turqueti, R. Rivera, J. Chramowicz and A. Prosser, "Study of alternative serial powering systems for the future ILC tracker," FERMILAB-PUB-07-623-CD.

R. Raja, "An Experimental program for demonstrating precision jet energy measurement at the ILC," arXiv:0709.0927 [physics.ins-det].

A. Prosser, G. Cardoso, J. Chramowicz, J. Marriner, R. Rivera and M. Turqueti [SNAP Collaboration], "Data acquisition, storage and control architecture for the SuperNova Acceleration Probe," FERMILAB-CONF-07-097-CD.

Invited Talks:

W. Cooper, “SiD VXD and Tracker Integration”, CLIC Vertex Detector Meeting, CERN, May 20, 2010

H.E. Fisk, “Tests of Strip-scintillator, WLS Fiber, Pixelated Photon Detectors and Custom Electronics at the Fermilab MTest Beam”, 14^{th} International Conference on Calorimetry in High Energy Physics (CALOR 2010), Beijing, China, May 10-14, 2010

A. Para, “Summary of the 2^{nd} workshop on Material Development for the HHCAL detector concept”, 14^{th} International Conference on Calorimetry in High Energy Physics (CALOR 2010), Beijing, China, May 10-14, 2010

A. Para, “Detailed Studies of hadron shower modeling in GEANT4”, 14^{th} International Conference on Calorimetry in High Energy Physics (CALOR 2010), Beijing, China, May 10-14, 2010

A. Para, “Total Absorption Dual Readout Hadron Calorimeter for future lepton colliders”, 14^{th} International Conference on Calorimetry in High Energy Physics (CALOR 2010), Beijing, China, May 10-14, 2010

A. Para, G. Pauletta, “Corrections for Jet reconstruction in a realistic calorimeter”, 14^{th} International Conference on Calorimetry in High Energy Physics (CALOR 2010), Beijing, China, May 10-14, 2010

M. Demarteau, H.E. Fisk, “Fermilab History in the Development of Crystals, Glasses and Si Detector Readout for Calorimetry”, Workshop on Material Development for the Homogeneous Hadronic Calorimeter Detector Concept, Institute of High Energy Physics, Beijing, China, May 9, 2010

A. Para, “Scintillating Materials for Homogenous Hadron Calorimetry” 2^{nd} Workshop on Material Development for the Homogeneous Hadronic Calorimeter Detector Concept, Beijing, China, May 9, 2010

P. Rubinov, H.E. Fisk, “Custom Electronics for SiPM devices: Making life in the test beam easier.”, 14^{th} International Conference on Calorimetry in High Energy Physics (CALOR 2010), Beijing, China, May 10-14, 2010

M. Demarteau, “Summary of the Workshop on Intelligent Trackers”, Workshop on Vertically Integrated Pixel Sensors (VIPS 2010), Pavia, Italy, April 22-24, 2010

G. Deptuch, "Front-End Electronics for 3D Technologies", Workshop on Vertically Integrated Pixel Sensors (VIPS 2010), Pavia, Italy, April 22-24, 2010

F. Khalid, “Front-End Electronics in SOI”, Workshop on Vertically Integrated Pixel Sensors (VIPS 2010), Pavia, Italy, April 22-24, 2010

R. Lipton, “A Vertically Integrated Module Design for Track Triggers at Super-LHC”, Workshop on vertically integrated pixel sensors (VIPS2010), Pavia, Italy, April 23, 2010.

M. Trimpl, “Pixel sensors using SOI technology at Fermilab”, Workshop on vertically integrated pixel sensors (VIPS2010), Pavia, Italy, April 23, 2010

R. Yarema, “3D Activities at Fermilab and Developments within the 3DIC Consortium, VIPS, April 22-24, 2010, Pavia - presentation

P. Rubinov, “Pixilated Photon Detectors”, International Design Study for Neutrino Factory, Fermilab, Batavia, Apr 9, 2010

M. Trimpl, “Recent SPi tests and setups”, seminar to the ATLAS-CMS power working group, CERN, March 31, 2010

M. Demarteau, “The Fermilab Test Beam Facility, a Status Report”, International Linear Collider Workshop LCWS10 and ILC10, Beijing, China, March 26-30, 2010

M. Demarteau, “The SiD Vertex and Tracking Detector, a Status Report”, International Linear Collider Workshop LCWS10 and ILC10, Beijing, China, March 26-30, 2010

M. Demarteau, “Status Report of the Detector Common Task Group”, International Linear Collider Workshop LCWS10 and ILC10, Beijing, China, March 26-30, 2010

G. Deptuch, "3D bonding at Ziptronix", 3D-IC Consortium Meeting, Marseille, France, March 17 – 19, 2010

G. Deptuch, "Vertically Integrated Pixel Chip VIP2B - Subreticle I', 3D-IC Consortium Meeting, Marseille, France, March 17 – 19, 2010

G. Deptuch, "Vertically Intgrated Pixel Imaging Chip – Subreticle J", 3D-IC Consortium Meeting, Marseille, France, March 17 – 19, 2010

R. Yarema, “3DIC Consortium MPW Run Review”, 3D-IC Consortium Meeting, Marseille, France, March 17 – 19, 2010

G. Deptuch, "Discussion of Suggestions for Process Improvements", SOI Collaboration Meeting, Fermilab, 4-5 March, 2010

F. Khalid, “3D SOI Design at Fermilab: MAMBO III”, SOI Collaboration Meeting, Fermilab, 4-5 March, 2010

W. Cooper, “The Design of Stable, Low-mass Support and Cooling Structures for a CMS Tracker Upgrade”, Workshop on Intelligent Trackers (WIT 2010), Berkeley, California, February 4, 2010 (submitted to JINST)

R. Lipton, “3D Technology for Intelligent Trackers”, Workshop on Intelligent Trackers (WIT

2010), Berkeley, California, February 4, 2010 (submitted to JINST)

M. Demarteau, “Summary of the Muon Collider Physics Workshop: Detectors”, The 2010 NFMCC Collaboration Meeting, Oxford, Mississippi, Jan 13-14, 2010

E. Eichten, “The Physics Landscape”, The 2010 NFMCC Collaboration Meeting, Oxford, Mississippi, Jan 13-14, 2010

R. Lipton, “3D Detector/Electronics Integration Technologies -Applications to LC, SLHC and Photon Sources”, Instrumentation Seminar, SLAC, Jan. 13 2010

R. Lipton, “3D Detector/Electronics Integration Technologies -Applications to ILC and SLHC”, Seminar, Bristol University, November 18, 2009

M. Demarteau, “Muon Collider Detector: Old Design and New Developments”, Muon Collider Physics Workshop, Fermilab, Batavia, November 10-12, 2009

H.E. Fisk, “Combined Test Beams and Dedicated ILC Testbeam Areas”; Linear Collider Testbeam Workshop, LAL/Orsay, France, November 5, 2009

P. Rubinov, “Electronics for the Minerva Experiment”, IEEE Nuclear Science Symposium, Orlando, Florida, Oct 27, 2009

P. Rubinov, “Pixilated Photon Detectors and possible uses at the LHC”, High Energy Physics Seminar, Wayne State University, Detroit, Michigan, Oct 23, 2009

M. Demarteau, “The Path Forward”, 2009 ALCPG Workshop, Albuquerque, New Mexico, September 29-October 3, 2009

H.E. Fisk, “Muon strip-scintillator system”, 2009 ALCPG Workshop, Albuquerque, New Mexico, September 29-October 3, 2009

A. Para, “Dual Readout in Totally Active Calorimeters”, 2009 ALCPG Workshop, Albuquerque, New Mexico, September 29-October 3, 2009

P. Rubinov, “Results and Plans for SiPM readout of Scintillators”, 2009 ALCPG Workshop, Albuquerque, New Mexico, September 29-October 3, 2009

R. Yarema, “The First 3D Multiproject run for HEP and Brookhaven's Contribution”, seminar, Brookhaven National Laboratory, October 14, 2009

R. Yarema, “First 3D Multiproject Run for HEP”, TWEPP Workshop, Paris, France, September 23, 2009

M. Demarteau, “Summary of Vertex 2009 Workshop”, Vertex 2009 conference, Veluwe, The Netherlands, September 13-18 2009

M. Trimpl, “Serial Powering Using the SPi chip”, Vertex 2009 conference, Veluwe, September 13-18, 2009

R. Lipton, “R&D on Vertically Integrated Electronics and Sensors”, 7th International "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors, Hiroshima, Japan, August 30, 2010.

A. Para, “Characterization of the MPPC performance as a function of temperature,” New Photodetectors 2009, Matsumoto, Japan, June 24, 2009.

M. Trimpl, “Development of Vertically Integrated Circuits for Particle Detectors,” 11th European Symposium on Semiconductor Detectors, Wildbad Kreuth, Germany, June 7-11, 2009.

A. Para, “Crystals for Hadron Calorimetry,” Inorganic Scintillators, SCINT09, Jeju, Korea, June 9, 2009.

M. Demarteau, “Rethinking the Muon Collider Detectors”, Low Emittance Muon Collider Workshop, Fermilab, Batavia, June 8-12, 2009

R. Yarema, “3D Design Activities at Fermilab and Associated Opportunities for Physics”, 11th Pisa meeting on Advanced Detectors, Elba, Italy, May 2009

J. Hoff, “FPHX: A New Silicon Strip Readout Chip for the Phenix Experiment at RHIC,” Front End Electronics Conference, Montauk, New York, May 19, 2009.

G. Deptuch, “Front End Electronics using 3D Integrated Circuits", Front End Electronics Conference, Montauk, New York, May 18, 2009.

M. Trimpl, “Serial Powering for Front End Electronics”, Front End Electronics Conference, Montauk, New York, May 19, 2009.

R. Lipton, “SiD Detector R&D,” Meeting of the Spanish Linear Collider R&D Consortium, May 2009.

M. Demarteau, “Tracking and Vertexing in the SiD Detector Concept,” Joint ACFA Physics and Detector Workshop and GDE Meeting, Tsukuba, Japan, April 17-21, 2009.

M. Demarteau, “Status Report of the ILC Detector R&D Common Task Group,” Joint ACFA Physics and Detector Workshop and GDE Meeting, Tsukuba, Japan, April 17-21, 2009.

G. Deptuch, “Development of SOI sensors at Fermilab”, First international conference on Technology and Instrumentation in Particle Physics, Tsukuba, March 12-17, 2009

R. Yarema, “Development of vertically integrated circuits for vertex detectors″, First international conference on Technology and Instrumentation in Particle Physics, Tsukuba, March 12-17, 2009

R. Lipton, “Application of Vertically Integrated Electronics and Sensors (3D) to Track Triggers,” ACES Meeting, CERN, March 2009.

L. Spiegel, “The MCz Beam Testing Program,” 4th Trento Workshop on Advanced Silicon Radiation Detectors, Trento, Italy, February 17-19, 2009.

M. Demarteau, “Muon Collider Detector Design Development”, The 2009 NFMCC Collaboration Meeting, Berkeley, California, January 25–28, 2009

E. Eichten, “Strengthening the Physics Case for a Muon Collider”, The 2009 NFMCC Collaboration Meeting, Berkeley, California, January 25–28, 2009

R. Yarema, “3D Technology, An Overview”, seminar, Argonne National Laboratory, Jan 21, 2009

M. Trimpl, “First Results of SOI-based integrated detector and electronics at Fermilab,” International Linear Collider Workshop, Chicago, Illinois, November 16-20, 2008.

M. Demarteau, “‘Vision’ for Micro Pattern Gas and Silicon Detectors for Tracking,” IEEE Nuclear Science Symposium, Dresden, Germany, October 19-25, 2008.

A. Para, “Characterization of Pixelized Photon Detectors,” IEEE Nuclear Science Symposium, Dresden, Germany, October 19-25, 2008.

A. Para, “High Resolution Hadron/Jet Calorimeter: Totally Active Calorimeter with Dual Readout,” IEEE Nuclear Science Symposium, Dresden, Germany, October 19-25, 2008.

A. Para, “Testing Hadron Shower Simulation Codes with Total Absorption Calorimeters,” IEEE Nuclear Science Symposium, Dresden, Germany, October 19-25, 2008.

R. Yarema, “The Other Option - 3D Circuits”, IEEE Nuclear Science Symposium, Dresden, Germany, October 19-25, 2008.

G. Deptuch, “Test Results from the VIP Chip”, Pixel 2008 Workshop, Fermilab, Batavia, September 23-26, 2008.

R. Yarema, “3D Technology Plans at Fermilab”, Pixel 2008 Workshop, Fermilab, Batavia, September 23-26, 2008.

M. Trimpl, “The SPI as an integrated power management device for serial powering,” Topical Workshop on Electronics for Particle Physics, Naxos, Greece, September 15-19, 2008.

R. Lipton, “Vertex R&D and experience at FNAL,” Belle Upgrade Workshop, July 2008.

M. Demarteau, “R&D on Pixel Detectors at Fermilab,” International Linear Collider ECFA Workshop, Warsaw, Poland, June 9-12, 2008.

M. Demarteau, “Tracking Status in the SiD Detector Concept,” International Linear Collider

ECFA Workshop, Warsaw, Poland, June 9-12, 2008.

R. Lipton, “New Vertex Detector Technologies,” seminar at the University of Chicago, June 2008.

A. Para, “Photodetectors for dual readout calorimetry,” Workshop on Trends in Photon Detectors for Particle Physics and Calorimetry, Trieste, Italy, June 3-4, 2008.

A. Para, “High resolution homogeneous hadron calorimetry,” Workshop on Trends in Photon Detectors for Particle Physics and Calorimetry, Trieste, Italy, June 3-4, 2008.

R. Lipton, “Radiation Effects on Detectors and Electronics,” Beam Instrumentation Workshop, Lake Tahoe, May 2008.

R. Yarema, G. Deptuch, “3D and SOI Integrated Circuit Design at Fermilab for HEP and Related Applications”, 2008 NSLS/CFN Users Meeting, Workshop on Detectors, Brookhaven, May 21, 2008

W.E. Cooper, “Integration Issues for a Vertex Detector at the ILC,” ILC Vertex Workshop, Menaggio, Italy, April 21-24, 2008.

R. Yarema, “3D Technology Issues and On-going Developments at Fermilab”, ILC Vertex Workshop, Menaggio, Italy, April 21-24, 2008.

A. Para, “Requirements for Materials to be Used to Construct Homogeneous Total Absorption Hadron Calorimeter,” Workshop on Materials for Homogeneous HCAL, SICCAS, Shanghai, February 20, 2008.

M. Demarteau, “3D Integrated Technology at Fermilab, Activities and Plans”, 3D Integrated Technology Perspectives, First workshop on LHC-ILC prospects, Ecole Polytechnique, Palaiseau, France, 29-30 November 2007

R. Yarema, “Review of 3D Related Technologies for HEP”, 3D Integrated Technology Perspectives, First workshop on LHC-ILC prospects, Ecole Polytechnique, Palaiseau, France, 29-30 November 2007

J. Hoff, “VIP1: A 3D Integrated Circuit for Pixel Applications in High Energy Physics,” Nuclear Science Symposium, Honolulu, Hawaii, November 2008.

R. Lipton, “New Vertex Detector Technologies,” seminar at Northwestern University, November 2007.

R. Lipton, “ILC: Thoughts, Issues and R&D,” Vertex 2007, Lake Placid, New York, October 2007.

M. Demarteau, “ILC Detector R&D,” Topical Workshop on Electronics for Particle Physics

(TWEPP) Conference, Prague, Czech Republic, September 3-7, 2007.

A. Para, “Characterization of the Response of Geiger-Mode Avalanche Photodiodes,” International Workshop on New Photodetectors (PD07), Kobe, Japan, June 2007.

R. Lipton, “Vertex Detector System Design,” DESY Linear Collider Workshop, May 2007.

R. Lipton, “SOI, 3D Electronics and Thinned Detectors,” seminar at Oxford University, May 2007.

R. Lipton, “SOI, 3D and Thinned Detectors,” seminar at Cornell University, April 2007.

Appendix:
Staff involved in Lepton Collider based Research

Scientists

Alan Bross
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Marcel Trimpl
Marcos Turqueti
Raymond Yarema
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Engineering Physicists

Anatoly Ronzhin
Paul Rubinov

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No one listed above is “full time” on Lepton Collider based Research